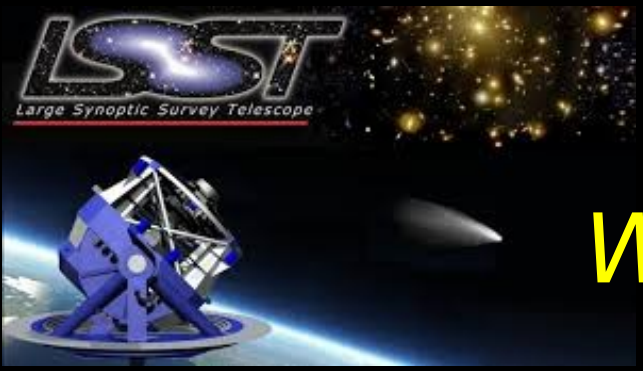
EUCLID

KECK

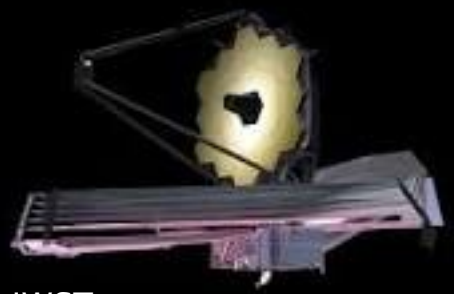
Optical/IR – the Big Picture

Warrick Couch, AAO

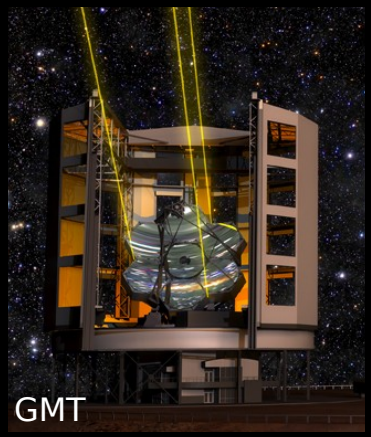


LSST

VISTA/4MOST



JWST



GMT

Australian Government Department of Industry & Science

SKA – Highest Science Priorities

Science Goal	SWG	Objective	SWG Rank
1	*CD/EoR*	Physics of the early universe IGM - I. Imaging	1/3
2	*CD/EoR*	Physics of the early universe IGM - II. Power spectrum	2/3
4	*Pulsars*	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection	1/3
5	*Pulsars*	High precision timing for testing gravity and GW detection	1/3
13	*HI*	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8	1/5
14	*HI*	High spatial resolution studies of the ISM in the nearby Universe.	2/5
15	*HI*	Multi-resolution mapping studies of the ISM in our Galaxy	3/5
18	*Transients*	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4
22	*Cradle of Life*	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5
27	*Magnetism*	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
32	*Cosmology*	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5
33	*Cosmology*	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
37 + 38	*Continuum*	Star formation history of the Universe (SFHU) – I+II. Non-thermal & Thermal processes	1+2/8

SKA Science Priority Outcomes document

SKA Science Priorities – Optical/IR Synergies

SKA1-LOW

Sci Priority	Approach/method	Opt/IR Synergy	Opt/IR observations
• Cosmic Dawn/EoR	Detect/characterize ionized structures and their power spectrum over EoR	Determining the redshift and sources of ionization	Ultra-deep imaging & spectr (8m, ELT, JWST)
• Pulsars	Detection & high-precision timing for tests of gravity and GW detection	Multi-messenger follow-up of GW events	Rapid ToR imaging and possibly spectr (any)
• Transients	Detection, localisation and redshift determination of coherent bursts to z~2	Association with galaxy and cluster halos.	Deep imaging, phot-z, spec-z (LSST, EUCLID)

SKA Science Priorities – Optical/IR Synergies

SKA1-MID

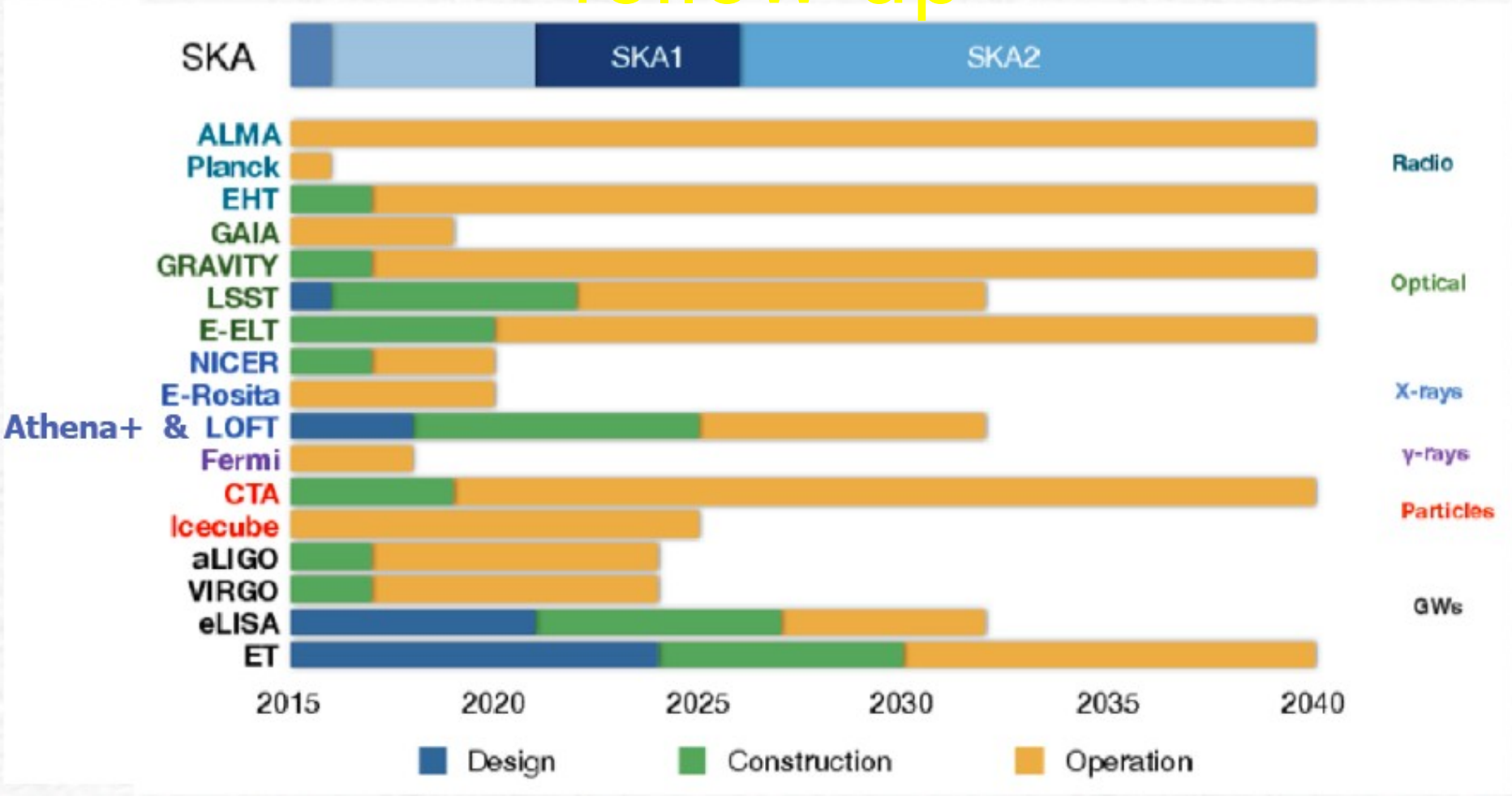
Sci Priority	Approach/method	Opt/IR Synergy	Opt/IR observations
• Pulsars	Detection & high-precision timing for tests of gravity and GW detection	Multi-messenger follow-up of GW events	Rapid ToR imaging and possibly spectroscopy (any)
• Transients	Detection, localisation and redshift determination of coherent bursts to z~2	Association with galaxy and cluster halos.	Deep imaging, phot-z, spec-z (LSST, EUCLID)
• HI	Resolved HI kinematics & morphology of M* galaxies at z=0.5-0.8	Resolved stellar & ionized gas kinematics & morphology of the same galaxies	Spatially resolved IFU spectr + multi-band imaging (8m, ELT)
• HI	High spatial resolution studies of the ISM in nearby galaxies	Resolved stellar & ionized gas kinematics & morphology of the same galaxies	Spatially resolved IFU spectr + multi-band imaging (AAT-HECTOR)
• HI	High spatial resolution studies of HI in the Galaxy and Magellanic Clouds	Comparison with components traced by optical/IR	Wide-field imaging and spec
• Cradle of life	Map dust grain growth in cm-size regime in proto-planetary disks	?	
• Cosmology	HI & continuum mapping over 30,000 deg² from z=0.2-3 to determine primordial non-Gaussian-ity and test gravity on super-horizon scales	Cross-correlation with optical/IR surveys to deliver much greater precision	Deep, wide-field red-shift surveys (4MOST, PFS, MSE)

Key optical/ir capabilities for maximizing synergies:

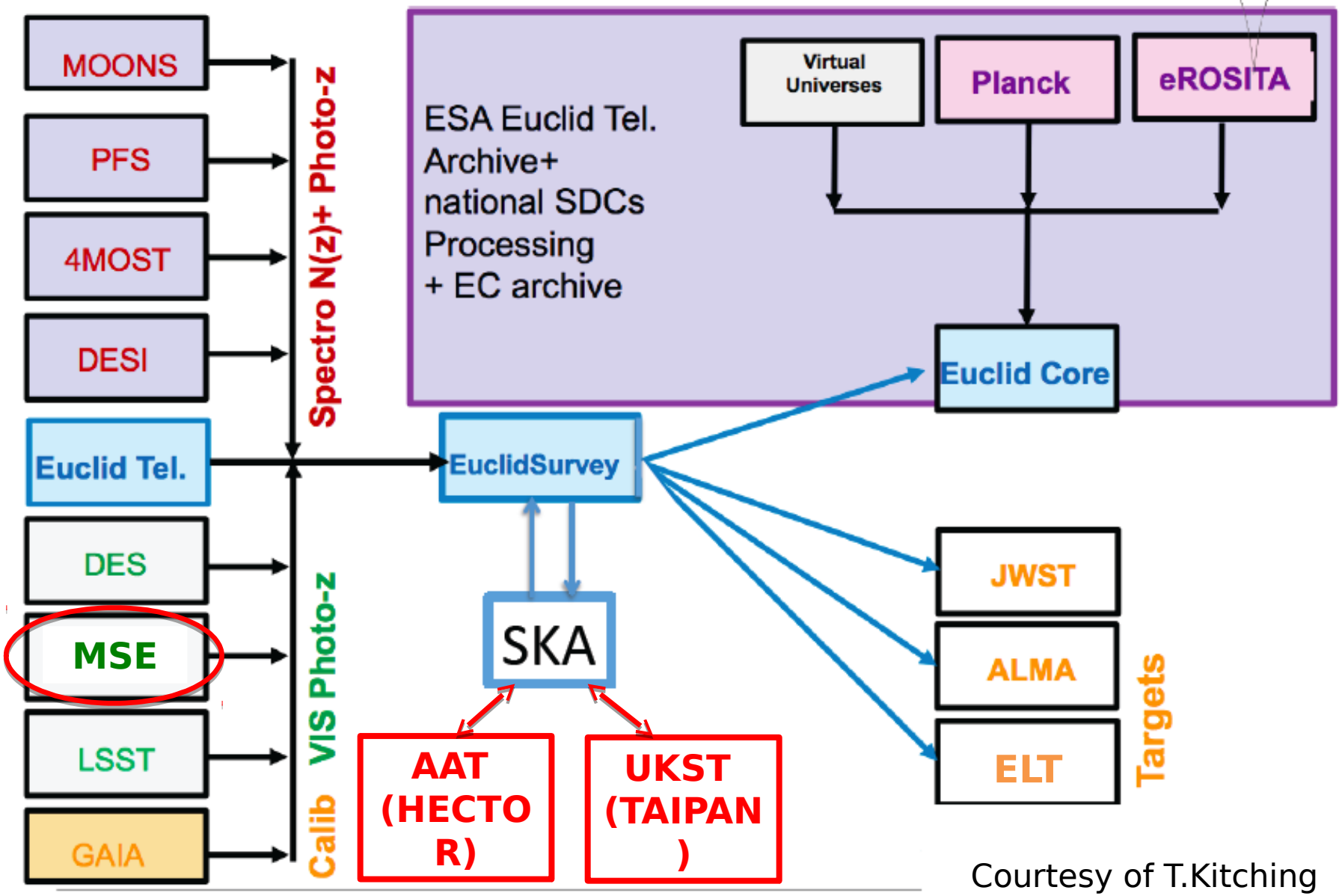
- **Imaging** – *deep, wide-field, multi-band (incl nb), temporal, high spatial resolution*
- **2D Spectroscopy** – *deep, wide-field, high-multiplex, S/N and spectral resolution sufficient for measurement of redshifts and SF/AGN diagnostics*
- **3D Spectroscopy** – *<u>spatially resolved</u> mapping of kinematics, SF & AGN activity, and stellar pops across individual galaxies*

CAASTRO-3D

Timeline for multi-wavelength follow-up

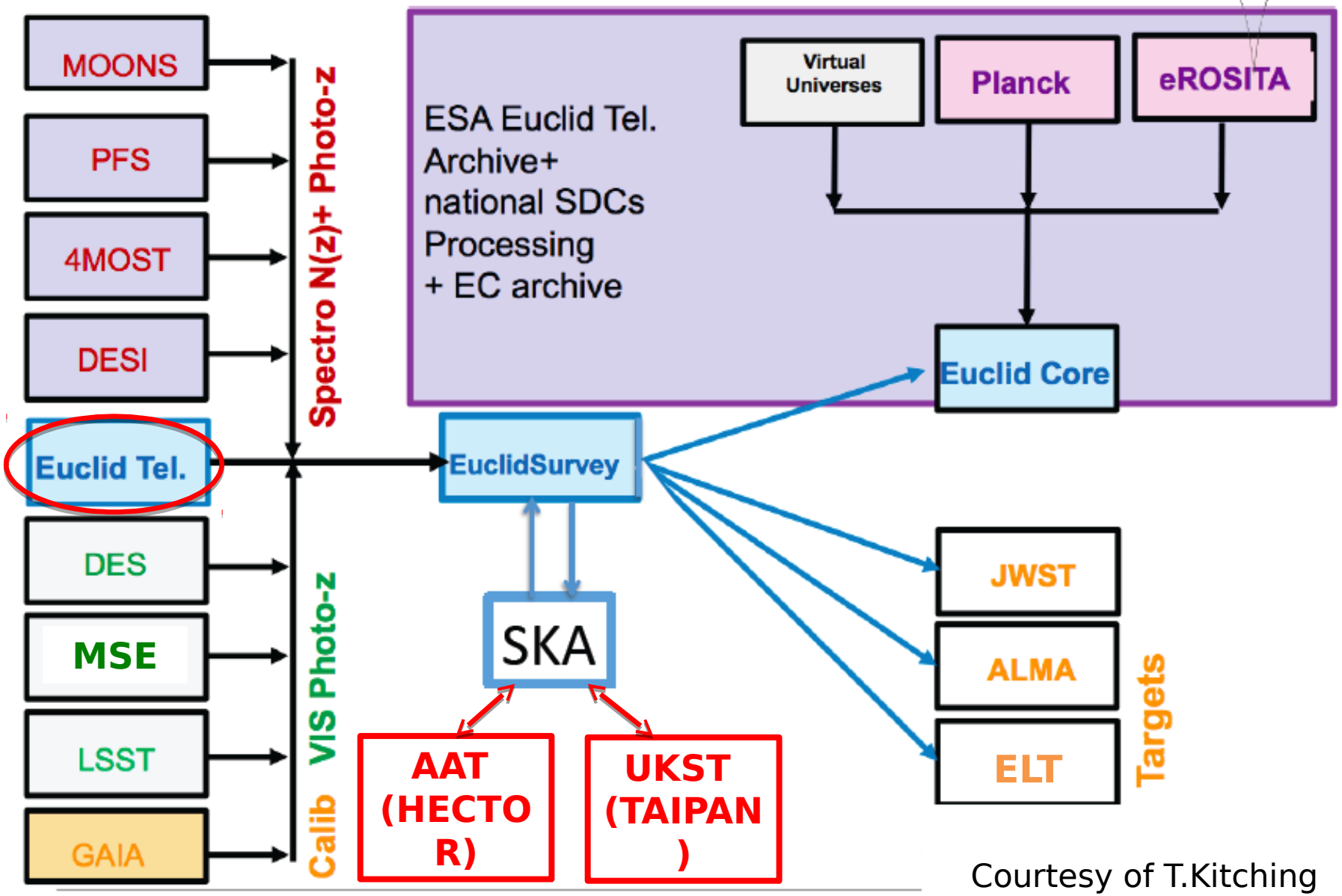


The Landscape of Synergies (a EUCLID-centric view)



Courtesy of T.Kitching

The Landscape of Synergies (a EUCLID-centric view)



Courtesy of T.Kitching

What is Euclid ?

Launch: 2020

SURVEYS In ~6 years		
	Area (deg2)	Description
Wide Survey	**15,000 deg²**	Step and stare with 4 dither pointings per step.
Deep Survey	**40 deg²**	In at least 2 patches of > 10 deg² 2 magnitudes deeper than wide survey

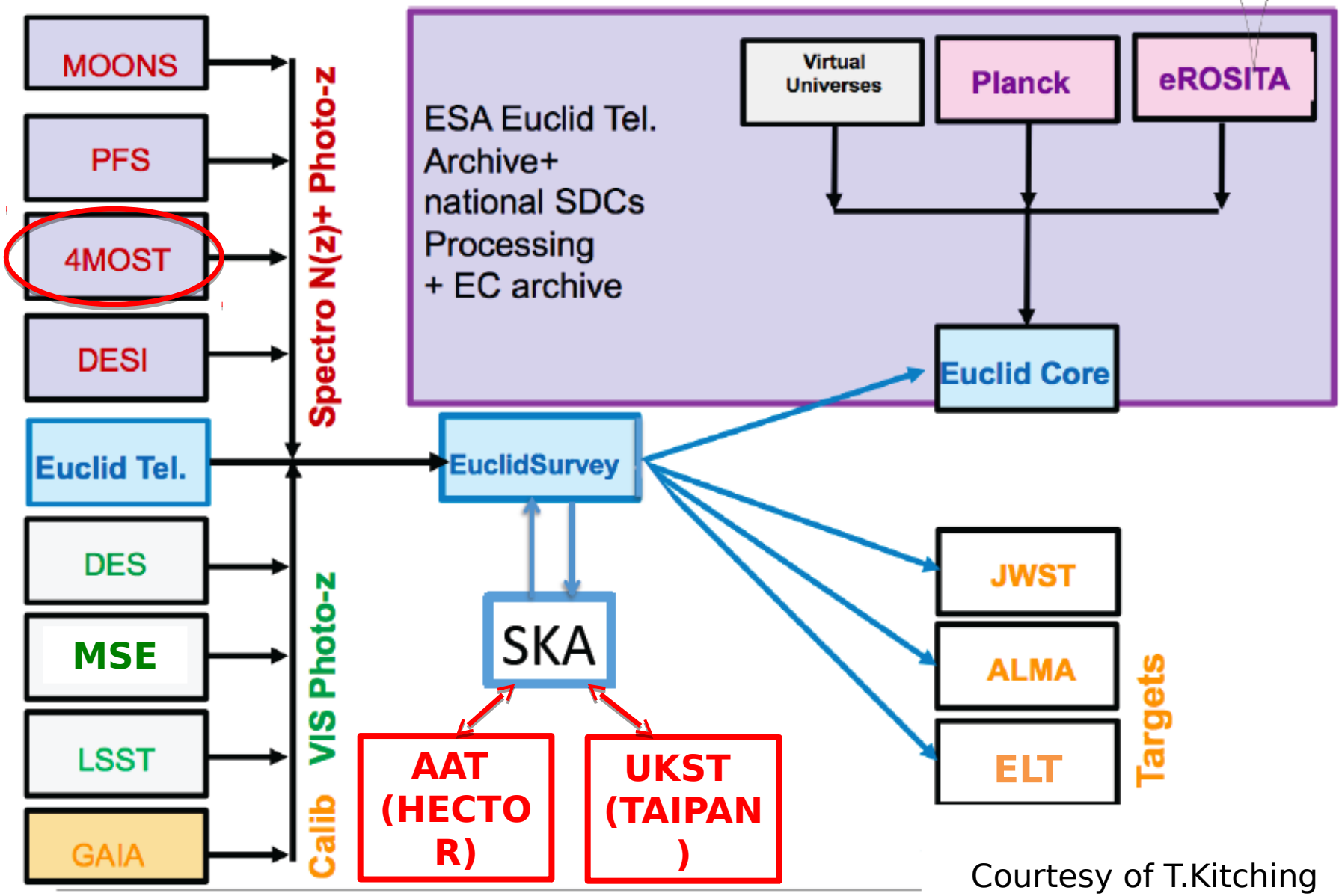
PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg²	0.763×0.722 deg²			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	$3\ 10^{-16}$ erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of $n = 1.5 \times 10^9$ galaxies			z of $n=2.5 \times 10^7$ galaxies	

Possibility other surveys: SN and/or μ-lens surveys, Milky Way (TBC): **after Mission PDR**

Ref: Euclid RB Laureijs et al arXiv:1110.3193

Primary mission: to map the geometry of the dark universe over the entire period dark energy played a significant role in accelerating the expansion (0<z<2)

The Landscape of Synergies (a EUCLID-centric view)



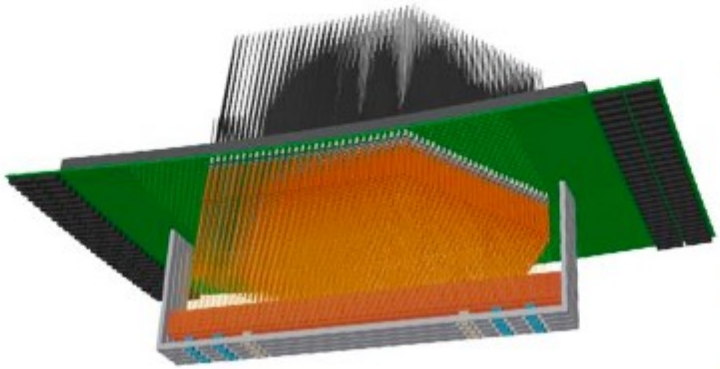
Courtesy of T.Kitching

4MOST

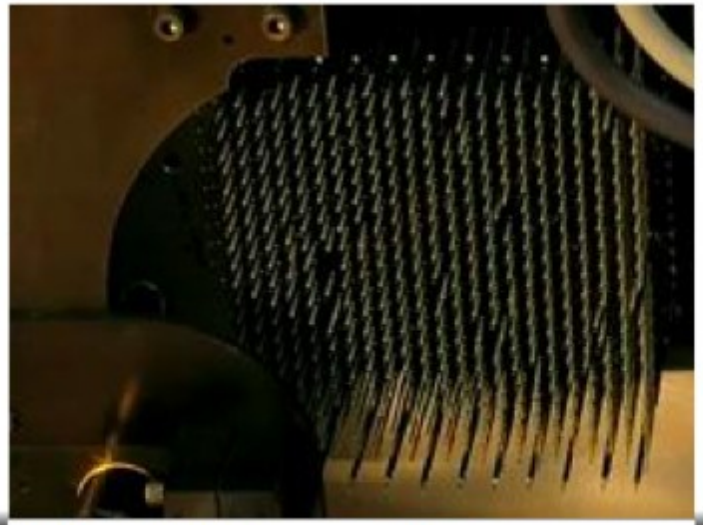
Instrument Specification

Specification	Design value
Field-of-View (hexagon)	>4.0 degree^2 (ø>2.5°)
Multiplex fiber positioner	~2400
Medium Resolution Spectrographs (2x) # Fibres Passband Velocity accuracy	R~5000–7000 1600 fibres 390-930 nm < 2 km/s
High Resolution Spectrograph (1x) # Fibres Passband Velocity accuracy	R~20,000 800 fibres 392-437 & 515-572 & 605-675 nm < 1 km/s
# of fibers in ø=2' circle	>3
Fibre diameter	ø=1.4 arcsec
Area (first 5 year survey)	>2h x 16,000 deg^2
Number of science spectra (5 year)	~75 million of 20 min

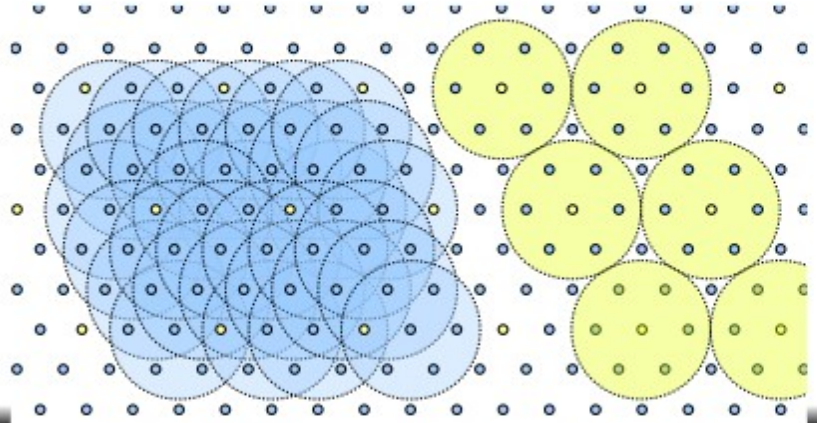
Tilting Spine (Echidna) positioner



- ~2400 fibres
- Large, overlapping patrol areas enables dense target packing and special high-resolution fibres
- Closest separation ~15 arcsec
- Reconfiguration time <2 min during science CCD readout



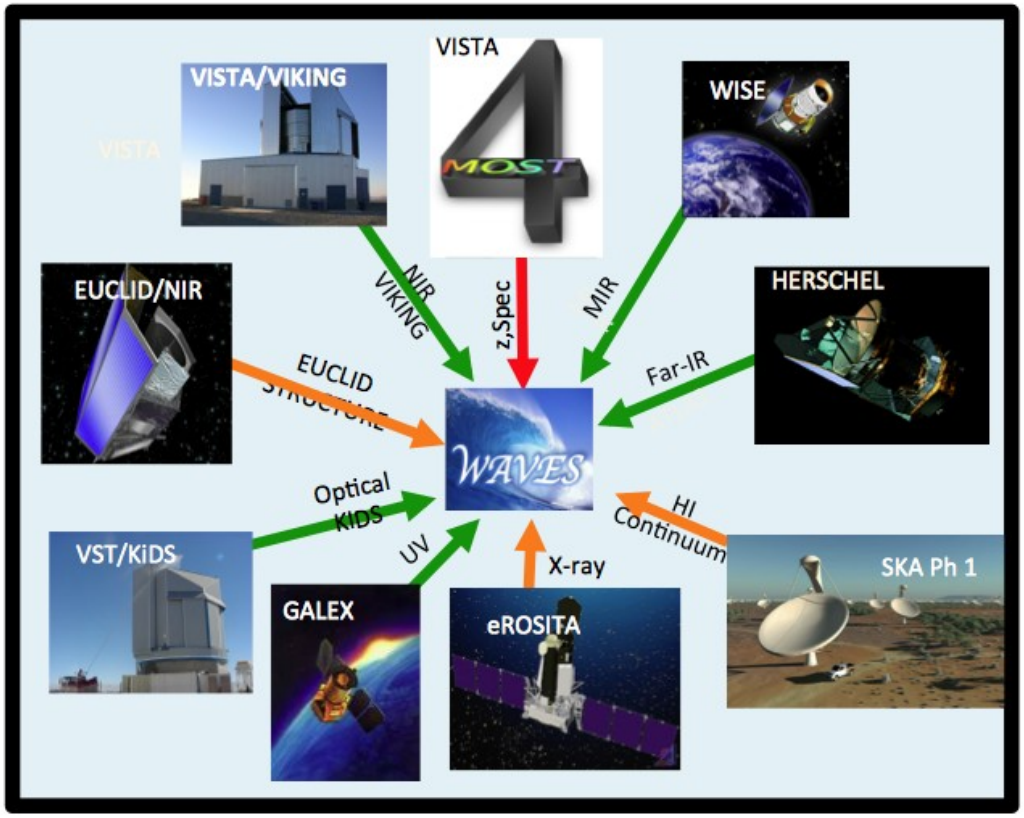
FMOS Echidna on Subaru

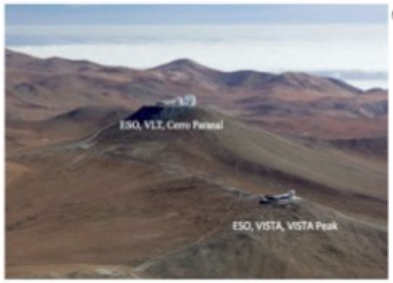


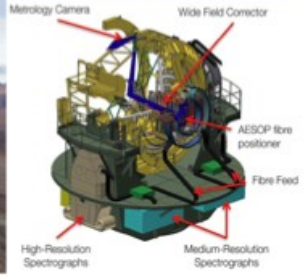
AAO, Sheinis et al., Paper 9151-67

WAVES
wide area VISTA
extra-galactic
survey

Wide Area VISTA Extra-galactic Survey







A 4MOST Design Reference Survey

2-4 million galaxies

WIDE (700 sq deg):

- r<22 (photo-z < 0.2)
- VST KiDS South

DEEP (100 sq deg):

- r<22
- GAMA23 (VST KiDS)

CDM v WDM

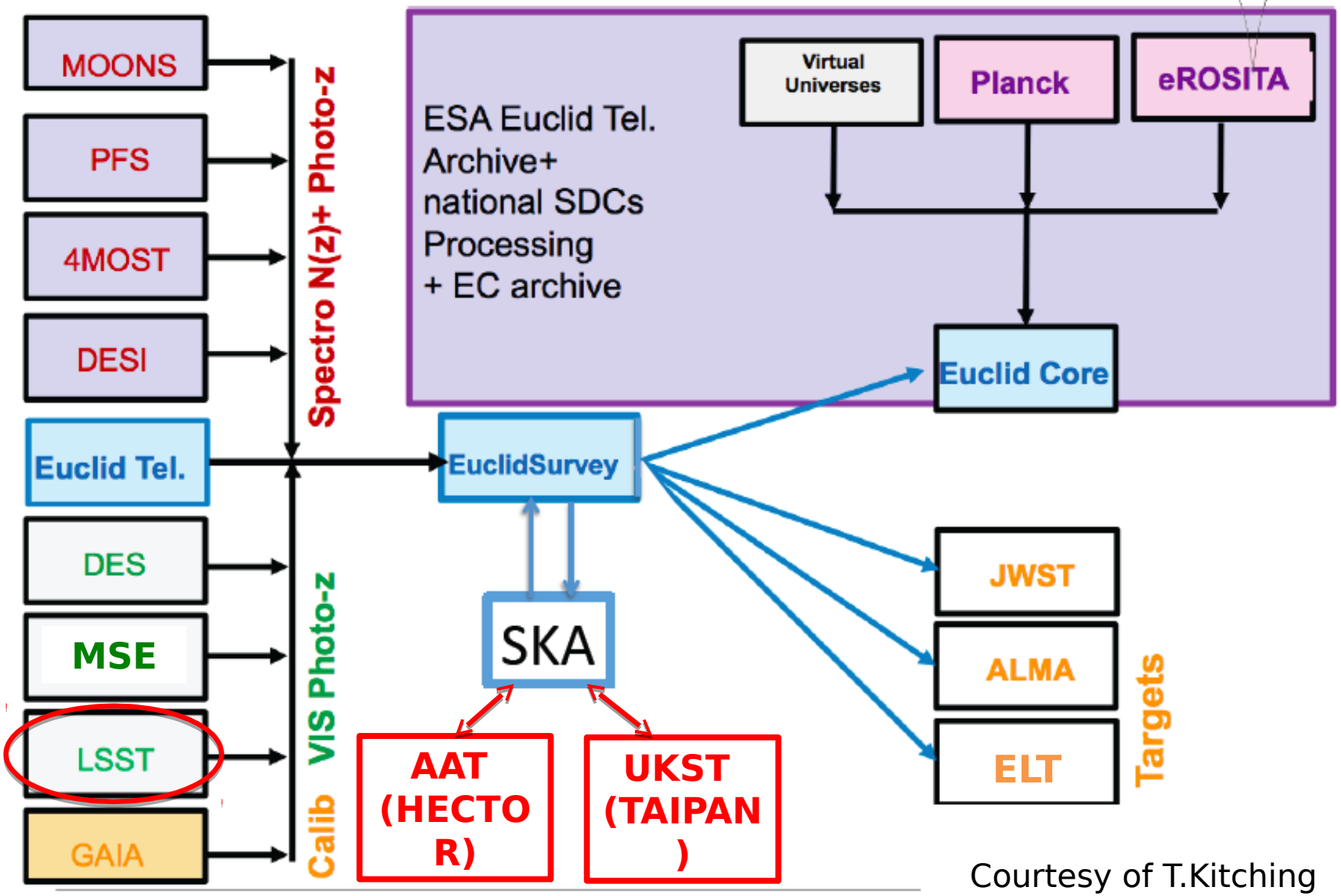
85,000 groups (Wide)

50,000 groups (Deep)

Mass, Energy, Structure to z=1

Deep = 75x zCOSMOS

The Landscape of Synergies (a EUCLID-centric view)



Courtesy of T.Kitching

The LSST

Contiguous overlapping imaging of over half the sky

6 bands (ugrizy, 320–1050 nm)

50 PB imaging data

15 PB catalog database

~15 TB of raw imaging /nt

Effective diameter of 6.5m

3.2 Gigapixels

Large field of view (9.6 deg^2)

0.2×0.2 $arcsec^2$ pixels

The LSST

Taking an Inventory of the Solar System
Mapping the Milky Way
Exploring the Transient Optical Sky
Probing Dark Energy and Dark Matter

Cerro Pachón in northern Chile

First light around 2021
First public data releases around 2023

Galaxy Evolution

SKA will probe e.g. AGN and SF history over cosmic time and wide area

Redshifts and stellar masses from LSST

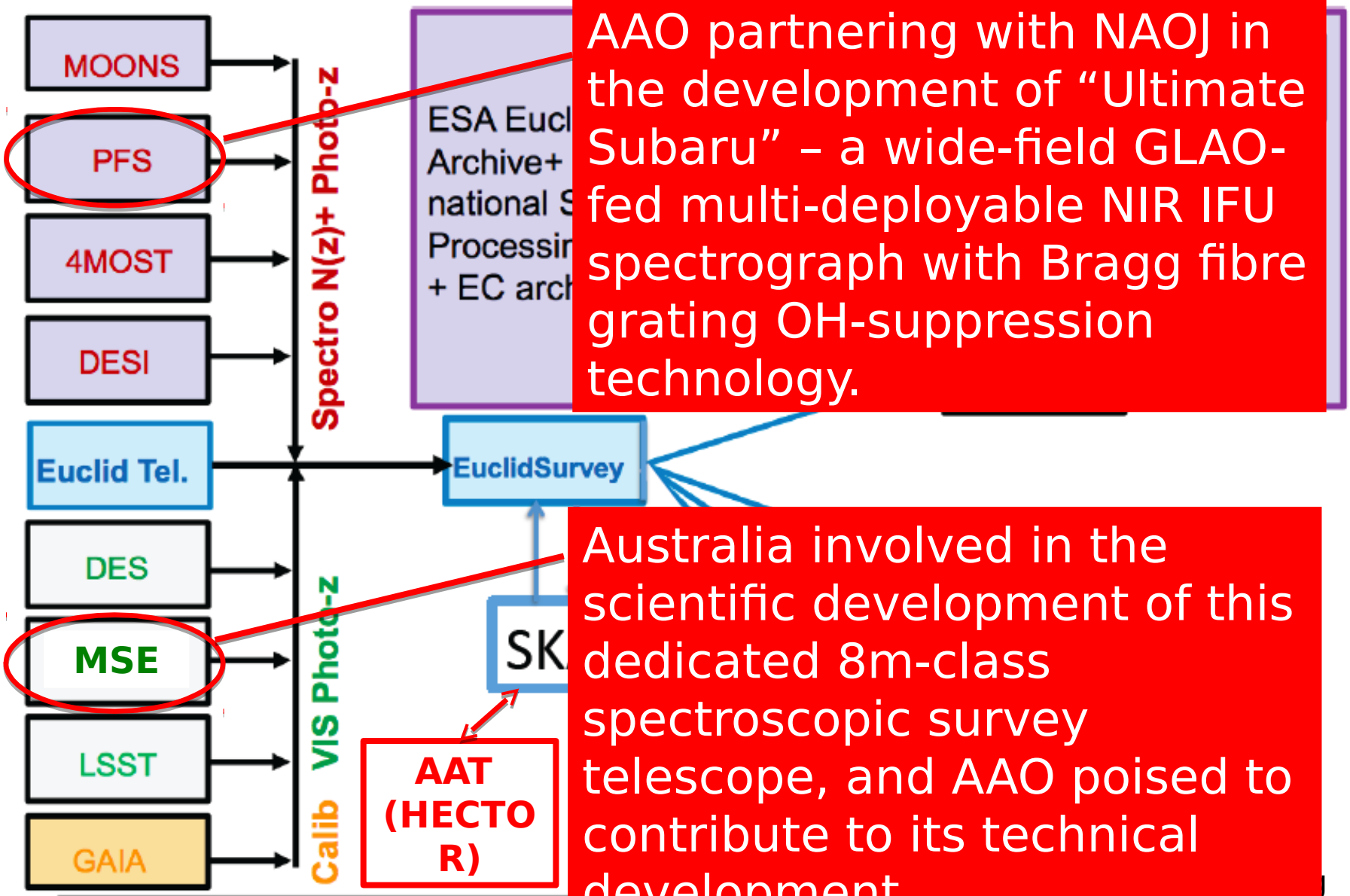
Pathway from neutral (SKA HI) to molecular gas (ALMA) to star formation (SKA continuum, LSST).

NB deep drilling fields (9 sq deg) - will see objects at z>6 (match with CO redshifts from SKA band 5)

Australian membership of LSST

- Current membership/involvement in science planning phase via CAASTRO and ICRAR (MoA's providing access for ~20 astronomers + their postdocs & students)
- Community-wide access prior to and through the operations phase to be provided by AAO

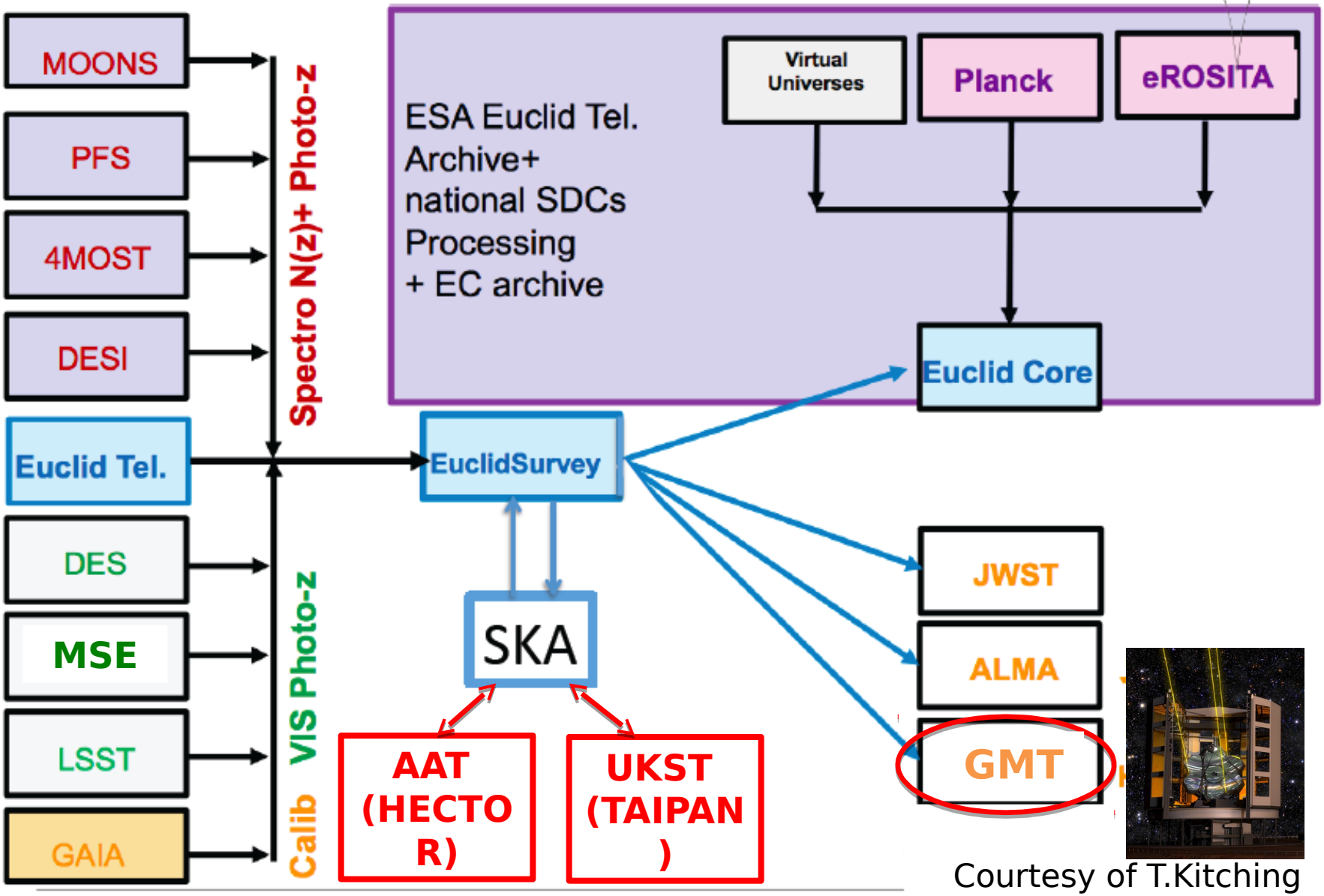
The Landscape of Synergies (a EUCLID-centric view)



AAO partnering with NAOJ in the development of "Ultimate Subaru" – a wide-field GLAO-fed multi-deployable NIR IFU spectrograph with Bragg fibre grating OH-suppression technology.

Australia involved in the scientific development of this dedicated 8m-class spectroscopic survey telescope, and AAO poised to contribute to its technical development.

The Landscape of Synergies (a EUCLID-centric view)

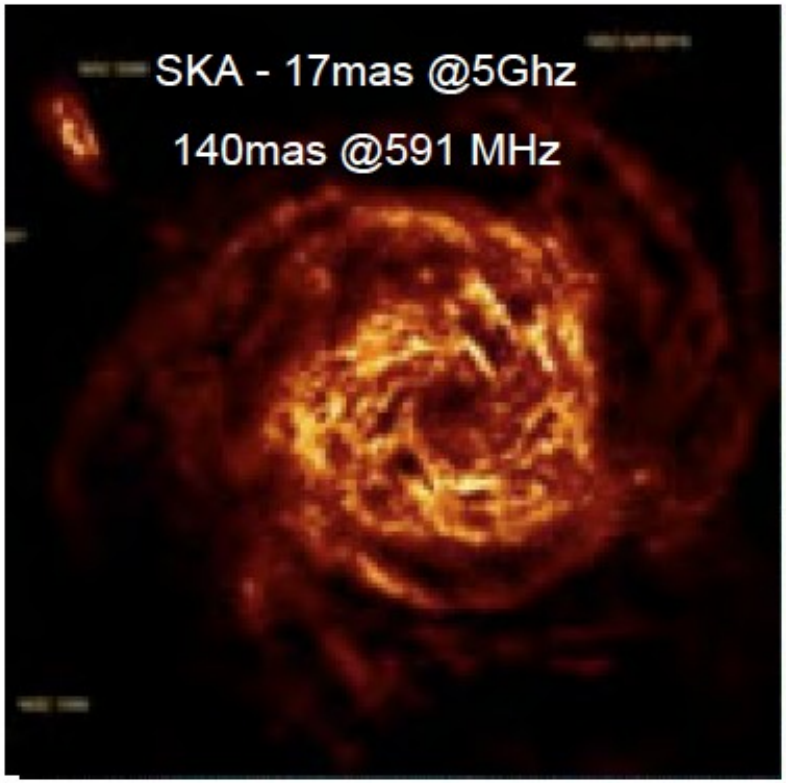


Courtesy of T.Kitching

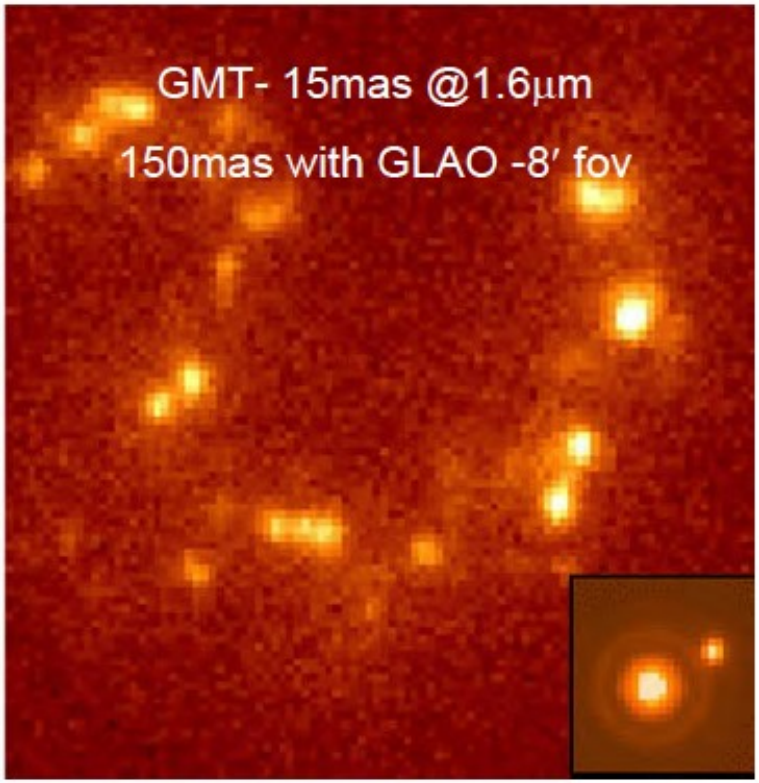
GMT Status

- Construction phase officially began on 25 March, with US$500M of legally-binding funding commitments signed by partners
- This will take place in 3 stages with following approximate time-line:
  - *Stage 1 (dome, telescope with 4/7 primary mirrors, 2 instruments) – mid-2020*
  - *Stage 2 (7/7 primary mirrors, partial AO, 3rd instrument) – mid-2022*

Internal Structure of Distant Galaxies



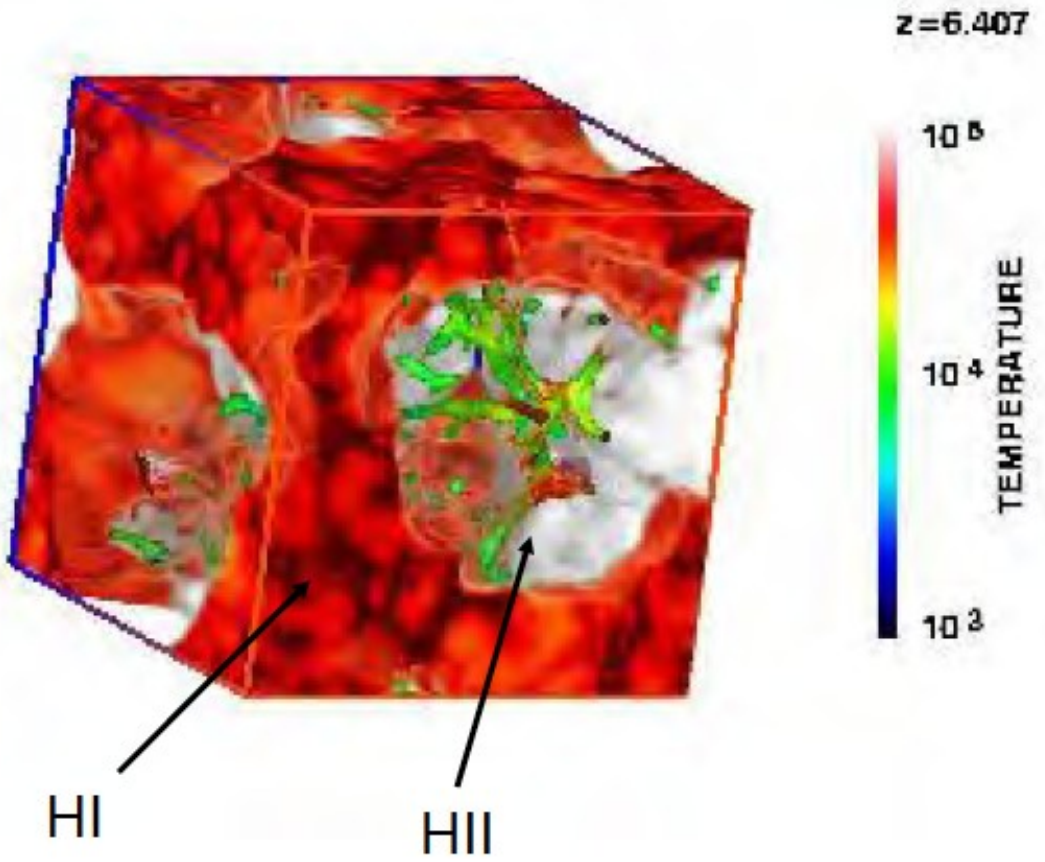
|------ 1 arcsecond ------|



Z = 0.1 HST Hα + Continuum

Z = 1.4 GMT @1.6μm 1-Hour

Probing the EOR with GMT & SKA

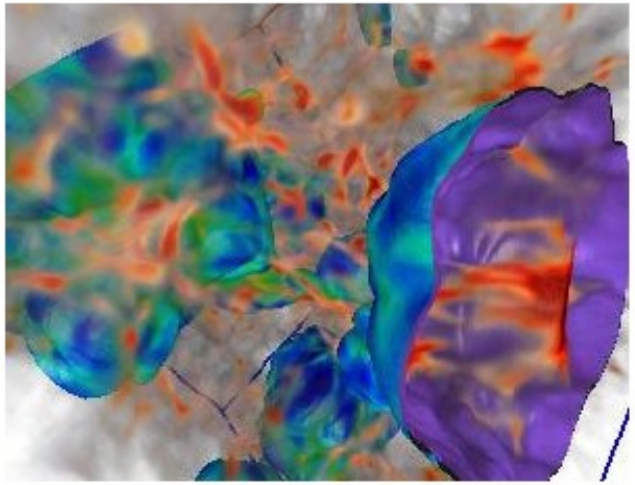


Key Questions:

- What is "the" redshift of reionization?
- What is the source(s) of ionization?
- How does the topology evolve with redshift?

Lyα as a probe of the EOR

How can ELTs explore the end of the Dark Ages?

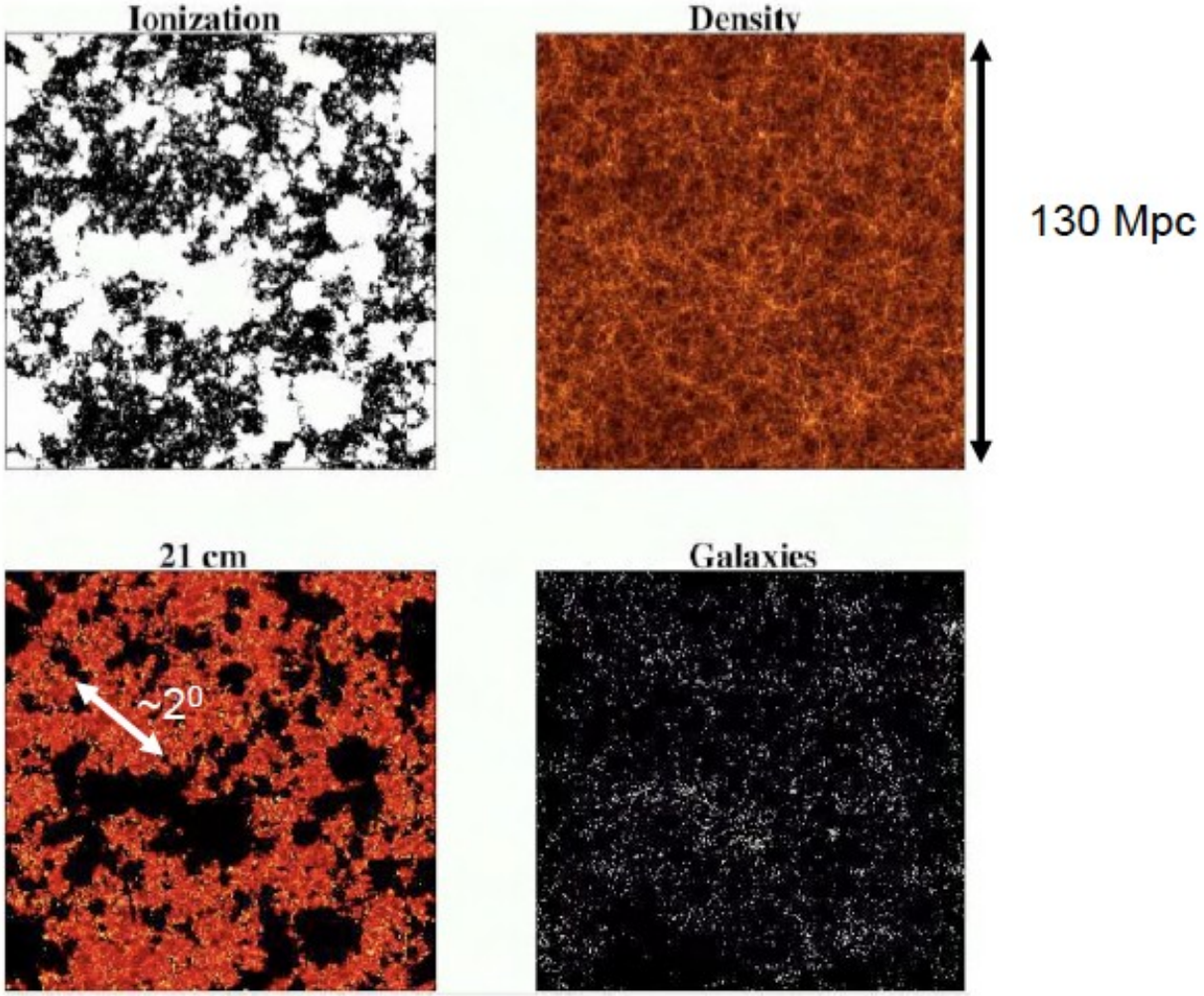


- Gunn-Peterson effect
- "Dark" GRBs ?
- Lyα florescence from boundary regions
- Evolution of the Lyα luminosity density
- Spatial correlation between SKA HI maps and LAEs
- Pencil beam surveys targeted from SKA

IGM Structure at z ~ 9

"Pencil beam" surveys can easily miss the important structures

SKA can provide the map needed to make an informed survey for Lyα at the end of the EOR.



Summary – key points

- Synergies with SKA truly multi-wavelength, and there will be numerous facilities (many new!) in each of the wavelength regions available to exploit these in the SKA era.
- The optical/IR region is no exception, with a rich collection of facilities that will provide deep imaging, spec-2D & spec-3D of the same large regions of sky covered by SKA.
- Australia will have access to many of these optical/ir facilities and with its strong and well-connected radio/optical communities, is well placed to exploit these synergies
- If funded, CAASTRO-3D will provide a critical role in coordinating and resourcing this activity, with